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(54) Title: CONFORMATION–SPECIFIC ANTI–VON WILLEBRAND FACTOR ANTIBODIES

(57) Abstract

The present invention is directed to antibodies and antibody fragments that bind specifically to the active conformation of human Von Willebrand factor. Most preferred are recombinantly produced single chain variable immunoglobulin fragments. Because the antibodies or antibody fragments act only at the sites of thrombus formation and do not interfere with the normal activity of circulating platelets, they are particularly well suited for use as antithrombotic agents in a wide variety of applications.

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Conformation-Specific Anti-von Willebrand Factor Antibodies

Field of the Invention

The present invention is directed to compositions containing one or more agents that recognize the active conformation of human von Willebrand and that inhibit the interaction between this factor and platelets. The compositions can be used either therapeutically or prophylactically to prevent thrombus formation in patients. Compositions may also be used diagnostically to detect sites where thrombosis is likely to occur.

Background of the Invention

Thrombosis occurring at atherosclerotic plaques is a major cause of morbidity and mortality in the United States. The initial event in thrombus formation is the adhesion of platelets to an injured or diseased arterial wall. Adhesion is enhanced and stabilized by a plasma protein, the von Willebrand Factor, which forms a bridge between components of the vessel wall and receptors on the platelet surface, primarily the glycoprotein Ib/IX/V complex. There are two unique features of this interaction that set it apart from adhesive events involving other cells and plasma proteins. First, the interaction of vWF with platelets is the only reaction that permits platelets to remain attached to vessel walls under the high shear/high flow conditions present in arteries, arterioles, and capillaries. Second, vWF is the only plasma adhesive protein which must undergo a conformation change before it is able to bind to its platelet receptor.

Attempts have been made to prevent thrombus formation by introducing either antibodies (*see, e.g.*, EP 747,060; WO 96/17078; and US 5,336,618) or peptides (*see, e.g.*, US 5,688,912; US 5,493,007; US 5,114,842; WO 93/16712; and EP 319,315) thatbind to platelet receptors. One problem with the use of such agents is that they are nonselective- interfering with the function of all circulating platelets. The development of an agent that acts specifically at sites of thrombosis to inhibit platelet adhesion would represent a clear advance in the treatment and prevention of stroke, myocardial infarction, and related conditions. Equally important, such an agent might be used diagnostically to identify sites where blood vessels are at risk of becoming occluded.

Summary of the Invention

Using recombinant DNA and phage display technology, murine anti-human vWF antibodies have been made which specifically recognize activated vWF and interfere with its ability to promote platelet adhesion. The antibodies act at sites of thrombus formation but do not bind to circulating, unactivated forms of vWF. This results in antithrombotic agents that are both safer and more efficacious.

In its first aspect, the invention is directed to a composition comprising an antibody that binds selectively to the active conformation of human vWF, thereby inhibiting its ability to interact with platelets. As used herein, "selective binding" means that an antibody has at least a tenfold, and preferably at least a hundredfold, greater affinity for vWF when it is in its active conformation compared to when it is unactivated. Relative affinity can be determined using standard binding assays in which vWF is examined both in the presence and absence of an activating agent such as Ristocetin. Unless otherwise indicated, the term "antibody" refers both to intact antibodies as well as to fragments, particularly to recombinantly engineered fragments, that retain their ability to bind to antigen. Inhibition of platelet binding occurs whenever there is a statistically significant reduction in the amount of vWF-induced platelet aggregation in the presence of antibody. In the most preferred embodiment, compositions contain recombinantly produced single chain variable region (ScFv) fragments of immunoglobulins directed against a vWF-A1 epitope. Typically, the ScFv fragment will be derived from the mouse and compositions designed for therapeutic administration will contain a pharmaceutically acceptable carrier.

In a second aspect, the invention is directed to a method of identifying an ScFv fragment that binds selectively to the active conformation of human vWF. The method involves immunizing an animal, preferably a mouse, with an immunogen (either a peptide or a nucleic acid encoding a peptide) derived from the A1 region of human vWF. After immunization, mRNA is isolated from the animal and used to produce an ScFv cDNA library in a bacteriophage capable of displaying the fragments. The library is then screened to identify phage expressing a fragment that binds selectively to the active conformation of vWF. Binding may be determined directly, in the presence and absence of an agent inducing vWF to assume an active conformation, or by examining the inhibition of vWF-induced platelet aggregation.

Once an appropriate phage has been identified, the DNA encoding the ScFv fragment may be recovered and subcloned in an expression vector. Finally, recombinant ScFv is produced in a host cell transformed with the vector and purified. The ScFv fragments obtained in this manner are part of the invention.

The present invention is also directed to a method for preventing thrombus formation in a patient by administering a pharmaceutical composition containing an antibody of the type discussed above, *i.e.*, an antibody binding selectively to the active conformation of human vWF. The pharmaceutical composition should be administered at a dosage sufficient to prevent the binding of activated vWF to platelets and may be administered either therapeutically or prophylactically. Therapeutically, the composition may be administered to a patient with an occluded blood vessel either alone or in conjunction with thrombolytic agents such as tissue plasminogen activator or streptokinase. Prophylactically, the compositon may be administered to patients at risk of thrombosis due to atherosclerosis or during medical procedures that carry a risk of vessel occlusion, *e.g.*, angioplasty, stent placement, or graft insertion.

Antibodies may also be detectably labeled and used in conjunction with imaging techniques to determine sites within the vasculature where thrombosis is likely to occur, *e.g.*, where there has been plaque rupture or blood vessel damage. Because ScFv fragments are missing regions of antibodies that are often responsible for nonspecific binding, these fragments are preferred for all *in vivo* diagnostic procedures.

Detailed Description of the Invention

The present invention is directed to antibodies that specifically recognize the activated conformation of vWF and prevent it from interacting with platelets. It encompasses methods for making ScFv conformation-specific fragments and methods for using such antibodies diagnostically, therapeutically and prophylactically.

A. Antibodies Selectively Binding to the Active Conformation of vWF

Methods for making and detecting antibodies have been described in numerous standard reference works such as: Harlow *et al.*, Antibodies, A Laboratory Manual, Cold Spring Harbor

Laboratory, N.Y. (1988); Klein, Immunology: The Science of Self-Nonself Discrimination (1982); Kennett *et al.*, Monoclonal Antibodies and Hybridomas: A New Dimension in Biological Analyses (1980); and Campbell, "Monoclonal Antibody Technology," in Laboratory Techniques in Biochemistry and Molecular Biology (1984). The process for producing conformation-specific antibodies may involve either injecting the intact vWF protein into an appropriate animal or, preferably, injecting short peptides made to correspond to regions of vWF that are believed to interact with platelets, *i.e.*, peptides from the A1 domain. As an alternative, nucleic acids encoding vWF or portions of vWF may be administered to animals (see, U.S. 5,589,466; U.S. 5,580,859; and U.S. 5,703,055). The preferred animal for immunization is the mouse.

The term "antibody" refers to monoclonal antibodies, polyclonal antibodies and to fragments of these antibodies that continue to bind to antigen. Polyclonal antibodies are derived from the sera of animals immunized with the antigen. Monoclonal antibodies can be prepared using hybridoma technology (Kohler *et al.*, *Nature 256*:495 (1975); Hammerling *et al.*, in Monoclonal Antibodies and T-Cell Hybridomas, Elsevier, N.Y. pp. 563–681 (1981)). In general, this technology involves immunizing an animal (usually a mouse) with antigen, extracting splenocytes from the immunized animal and then fusing the splenocytes with myeloma cells, *e.g.*, SP_2O cells. After fusion, the resulting hybridoma cells are selectively maintained in HAT medium and then cloned by limiting dilution (Wands *et al.*, *Gastroenterology 80*:225–232 (1981)). The cells obtained through such selection are then assayed to identify clones which secrete antibodies capable of binding specifically to the active conformation of vWF. Antigen-binding fragments may be produced by proteolytically cleaving intact antibodies using enzymes such as papain (to produce Fab fragments) or pepsin (to produced $F(ab')_2$ fragments).

Assays appropriate for measuring the binding of antibody to vWF are well known in the art. For example, radioimmunoassays or immunometric assays, also known as "two-site" or "sandwich" assays, may be used (*see* Chard, "An Introduction to Radioimmune Assay and Related Techniques," in Laboratory Techniques in Biochemistry and Molecular Biology, North Holland Publishing Co., N.Y. (1978)). In one variety of such assays, the antibody to be tested is immobilized on a solid support and then incubated with a solution containing detectably

labeled vWF in the presence and absence of an activator such as Ristocetin. Nonspecific binding may be determined by carrying out parallel incubations in the presence of an excess quantity of unlabeled vWF and activator. This should be subtracted from total binding, i.e., binding in the absence of unlabeled vWF, to arrive at the specific binding for each sample tested. Other steps such as washing, stirring, shaking, filtering, and the like may be included in the assays as necessary. Typically, wash steps are included after the separation of bound ligand from ligand remaining in solution and prior to the quantitation of binding, *e.g.*, by counting radioactive isotope. As an alternative, assays examining the ability of antibodies to inhibit the aggregation of platelets in the presence of activated vWF may be used.

It is highly desirable that antibodies identified as binding to the active conformation of vWF be reexamined in a concentration range sufficient to perform a Scatchard analysis on the results. This type of analysis is well known in the art and can be used for determining the affinity of an antibody for an antigen (*see, e.g.*, Ausubel *et al.*, Current Protocols in Molecular Biology, pp. 11.2.1–11.2.19 (1993); Laboratory Techniques in Biochemistry and Molecular Biology, Work *et al.*, N.Y. (1978)). Computer programs may be used to help in the analysis of results (*see, e.g.*, Munson, P., *Methods Eenzymol. 92:*543–577 (1983); McPherson, "Kinetic, EBDA Ligand, Lowry–A Collection of Radioligand Binding Analysis Programs," Elsevier-Biosoft, U.K. (19985)).

B. ScFv Fragments

ScFv fragments are proteins consisting of the V_L and V_H antibody polypeptide chains synthesized as a single chain with the carboxyl terminus of V_L linked by a peptide bridge to the amino terminus of V_H. Methods for recombinantly producing these peptides in *E. coli* are well known in the art (*see* Bird *et al.*, *Science 242*:423–426 (1988); Huston *et al.*, *Proc. Nat'l Acad. Sci. USA 85*:5879–5883 (1988); and de Kruif *et al.*, *J. Mol. Biol. 248*:97–105 (1995)). Although any method for generating these fragments is compatible with the present invention, the preferred method consists of immunizing mice with peptides derived from the A1 region of vWF. After immunization, splenic mRNA is harvested from the mice and used to produce a cDNA library in a bacteriophage which displays the ScFv fragments. Phage are then screened to determine those that interact specifically with the activated form of vWF. ScFv segments are recovered from these phage, incorporated into an expression vector, and cloned in *E. coli*.

The recombinant ScFv fragments produced by the bacteria may be purified and further tested for binding affinity to both activated and unactivated vWF.

Using this procedure, recombinant antibody fragments have been obtained that have three important characteristics: 1) they only bind to vWF that has been activated by prior immobilization or by exposure to an activating agent like Ristocetin; 2) they inhibit the binding of vWF to platelets as measured using a Ristocetin-induced platelet agglutination assay; and 3) they inhibit flow-dependent platelet adhesion to immobilize vWF. The selectivity of these fragments makes them suitable for use in pharmaceutical compositions designed for administration to patients as antithrombotic agents.

C. Therapeutic and Diagnostic Use of Antibodies

Pharmaceutical compositions containing antibodies specific for the active conformation of vWF may be used to treat or prevent coronary arterial ischemic syndromes, including unstable angina and acute myocardial infarction, as well as to treat cerebrovascular and peripheral vascular ischemia. The compositions may also be used in conjunction with therapeutic interventions such as stent placement, balloon angioplasty, or graft insertion.

Any route of administration and dosage form is compatible with the present invention and conformation-specific antibodies may be administered as either the sole activate agent or in combination with other therapeutically active drugs such as thrombolytics. In general, parenteral delivery using the intravenous, intraarterial, intramuscular, intraperitoneal, intracutaneous, or subcutaneous routes is preferred.

Dosage forms may be prepared using methods that are standard in the art (*see, e.g.*, Remington's Pharmaceutical Sciences, 16th ed., A. Oslo ed., Easton, PA (1980)). Active agents may be used in combination with any of the vehicles and excipients commonly employed in pharmaceutical preparations, *e.g.*, talc, gum arabic, lactose, starch, magnesium stearate, cocoa butter, aqueous or non-aqueous solvents, oils, paraffin derivatives, glycols, etc. Solutions can be prepared using water or physiologically compatible buffers, or organic solvents such as ethanol, 1,2-propylene glycol, polyglycols, dimethyl sulfoxide, fatty alcohols, triglycerides, partial esters of glycerine, and the like. Preferred parenteral compositions may be prepared

using conventional techniques and include sterile isotonic saline, water, 1,3-butanediol, ethanol, 1,2-propylene glycol, polyglycols mixed with water, Ringer's solution, etc.

The dosage of active agent to be administered to a patient will be determined using methods well known in the art and will depend upon a wide variety of clinical factors. By way of example, a typical pharmaceutical composition for injection may comprise 1 ml of sterile buffered water and 10 mg of antibody. A typical composition for intravenous infusion may comprise 250 ml of sterile Ringer's solution and 10 mg of protein. The compositions may be administered either prophylactically or therapeutically. In therapeutic applications, compositions are administered to a patient suffering from a disease or condition in an amount sufficient to produce a positive therapeutic effect. For example, in the case of angina, dosage should be adjusted to the point where pain is alleviated. For occluded vessels, it is expected that antibodies will be used in conjunction with one or more thrombolytic agents and dosage should be sufficient to achieve, at least partial, reperfusion.

Prophylactically, pharmaceutical compositions containing the conformation-specific antibodies are administered to a patient in order to prevent the onset of an unwanted disease or condition. Thus, compositions may be administered to a patient with atherosclerotic plaques to prevent thrombosis or to patients undergoing therapeutic procedures such as angioplasty to reduce the chance of vessel occlusion.

Antibodies may also be used diagnostically to identify sites of potential thrombus formation. This may be accomplished by labeling antibodies with an agent that is detectable by imaging techniques such as NMR, MRI, or CAT scans. ScFv fragments should be especially useful in this regard in that the portions of antibodies that are primarily responsible for nonspecific *in vivo* binding are not present in these molecules.

All references cited herein are fully incorporated by reference. Having now fully described the invention, it will be understood by those of skill in the art that the invention may be performed within a wide and equivalent range of conditions, parameters and the like, without affecting the spirit or scope of the invention or embodiment thereof.

What is Claimed is:

1. A composition comprising an antibody that binds selectively to the active conformation of human von Willebrand Factor (vWF) and wherein said antibody inhibits the binding of vWF to platelets.

2. The composition of claim 1, wherein said antibody is a single chain variable region immunoglobulin (ScFv) fragment.

3. The composition of claim 2, wherein said ScFv fragment is from the mouse.

4. The composition of any one of claims 1–3, further comprising a pharmaceutically acceptable carrier.

5. A method of identifying a single chain variable region immunoglobulin (ScFv) fragment that binds selectively to the active conformation of vWF, comprising:

a) immunizing an animal with an immunogen derived from the A1 region of human vWF;

b) isolating mRNA from the immunized animal of step a);

c) producing a cDNA library from the isolated mRNA of step b) in a bacteriophage capable of displaying ScFv fragments encoded by the cloned cDNA; and

d) screening the library of step c) to identify a bacteriophage displaying a ScFv fragment that binds selectively to the active conformation of vWF.

6. The method of making and ScFv fragment that binds selectively to the active conformation of vWF, comprising:

a) immunizing an animal with an immunogen derived from the A1 region of human vWF;

b) isolating mRNA from the immunized animal of step a);

c) producing a cDNA library from the isolated mRNA of step b) in a bacteriophage capable of displaying ScFv fragments encoded by the cloned cDNA; and

d) screening the library of step c) to identify a bacteriophage displaying a ScFv fragment that binds selectively to the active conformation of vWF.

e) subcloning the recombinant DNA encoding the ScFv fragment identified in step d) in an expression vector;

f) transforming a host cell capable of expressing recombinant ScFv with the expression vector of step e); and

g) purifying the recombinant ScFv produced by the host cell of step f).

7. The method of either claim 5 or 6, wherein the animal of step a) is a mouse.

8. The method of either claim 5 or 6, wherein the screening of step d) comprises determining whether said ScFv fragment binds to vWF in the presence and absence of an agent that induces vWF to assume an active conformation.

9. The method of claim 8, wherein said agent is Ristocetin.

10. The method of either claim 5 or 6, wherein the screening of step d) comprises determining whether said ScFv fragment inhibits the binding of vWF to platelets.

11. An ScFv fragment produced by the method of either claim 5 or 6.

12. A method of inhibiting the binding of human vWF to platelets, comprising contacting said human vWF with an antibody that binds selectively to the active conformation of vWF.

13. The method of claim 12, wherein said antibody is a ScFv fragment.

14. The method of claim 13, wherein said ScFv is from the mouse.

15. A method of preventing thrombus formation in a patient, comprising administering a pharmaceutical composition comprising an antibody that binds selectively to the active conformation of human vWF and that thereby prevents the binding of vWF to platelets, wherein said pharmaceutical composition is administered at a dosage sufficient to inhibit said thrombus formation.

16. The method of claim 15, wherein said antibody is a ScFv fragment.

17. The method of claim 16, wherein said ScFv fragment is from the mouse.

INTERNATIONAL SEARCH REPORT

Int. tional Application No
PCT/US 99/24503

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C07K16/36 A61K39/395 G01N33/68

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C07K A61K G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YAMAMOTO H ET AL: "Antagonism of vWF inhibits both injury induced arterial and venous thrombosis in the hamster." THROMBOSIS AND HAEMOSTASIS, (1998 JAN) 79 (1) 202-10. , XP000876714 abstract	1,4,12, 15
Y		2,3, 5-11,13, 14

Y	VAUGHAN T ET AL: "Human antibodies with sub-nanomolar affinities isolated from a large non-immunized phage display library." NATURE BIOTECHNOLOGY, (1996 MAR) 14 309-14., XP002084763 abstract	2,3, 5-11,13, 14

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
16 February 2000	09/03/2000
Name and mailing address of the ISA	**Authorized officer**
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INTERNATIONAL SEARCH REPORT

Inte .ional Application No
PCT/US 99/24503

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	YUAN, H. (1) ET AL: "A structural and functional study of the von Willebrand factor A1 domain using A1 and A3 domain-specific antibodies." BLOOD, (1995) VOL. 86, NO. 10 SUPPL. 1, PP. 70A. MEETING INFO.: 37TH ANNUAL MEETING OF THE AMERICAN SOCIETY OF HEMATOLOGY SEATTLE, WASHINGTON, USA DECEMBER 1-5, 1995 , XP000876716 abstract	1,4,12
X	EP 0 795 608 A (AJINOMOTO CO) 17 September 1997 (1997-09-17) claims 1-14	1,4,12, 15
A	LAFAYE P ET AL: "Biologically active human anti-crotoxin scFv isolated from a semi-synthetic library." IMMUNOTECHNOLOGY, (1997) 3 117-25., XP004088468 abstract	1-17
A	ADAMS C ET AL: "Development of potent agonist antibodies to c-Mpl from a human scFv phage display library." BLOOD, (1995 NOV 15) 90 (10) 55A, XP002095743 abstract	1-17
A	HOYLAERTS M F: "Platelet-vessel wall interactions in thrombosis and restenosis role of von Willebrand factor." VERHANDELINGEN - KONINKLIJKE ACADEMIE VOOR GENEESKUNDE VAN BELGIE, (1997) 59 (3) 161-83. REF: 68 , XP000876711 the whole document	1-17
P,X	MCLEOD, A. G. ET AL: "Identification of a conformation-specific antibody to the vWF-A1 domain by repertoire cloning." BLOOD, (NOV. 15, 1998) VOL. 92, NO. 10 SUPPL. 1 PART 1-2, PP. 501A. MEETING INFO.: 40TH ANNUAL MEETING OF THE AMERICAN SOCIETY OF HEMATOLOGY MIAMI BEACH, FLORIDA, USA DECEMBER 4-8, 1998 THE AMERICAN SOCIETY OF HEAMATOLOGY. , XP000876694 abstract	1-17

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 99/24503

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

Remark: Although claims 12-14 (partially, as far as in vivo method is concerned) and 15-17 are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the compound/composition.

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int. tional Application No
PCT/US 99/24503

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0795608 A	17-09-1997	FI 972279 A	29-07-1997
		NO 972253 A	29-07-1997
		US 5916805 A	29-06-1999
		CA 2206423 A	06-06-1996
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		WO 9617078 A	06-06-1996